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ENERGY COSTS OF GOODS AND SERVICES

IN 1967

INCLUDING SOLAR ENERGY INPUTS AND LABOR AND GOVERNMENT SERVICE FEEDBACKS

by

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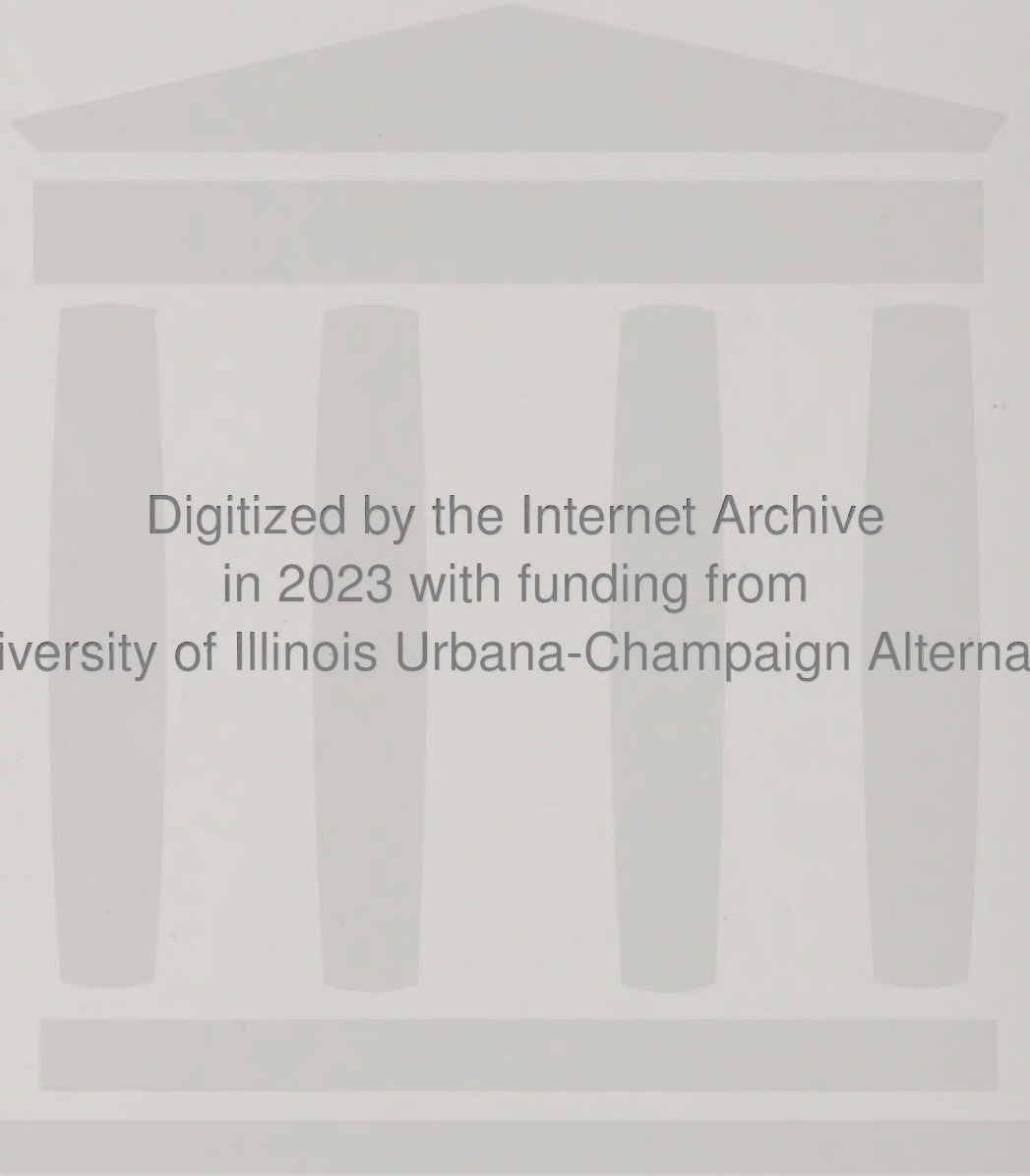
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The concepts, whose surfaces are barely scratched in this report, represent an attempt to integrate the ideas and techniques of B. Hannon and R. Herendeen at Illinois and H. T. Odum at Florida. I wish to thank S. Turetzky and T. Milke for guidance and computer programming, Veronica Soltys and Linda Yates for typing drafts, Diane Goddard for editing, and Pam King for typing the final copy. I am also grateful to B. Hannon, R. Herendeen and Flora Wang for reading the drafts and providing many useful comments.

ABSTRACT

The total energy cost of producing goods and services may be obtained from the manipulation of input-output statistics. To arrive at the total energy cost, two requirements must be met:

- 1) the total energy input to the economy must be specified (including the fossil fuel, mineral, and solar energy inputs), and
- 2) the system boundaries must be drawn so that only energy or embodied energy enters the system as an input.

This paper presents some modifications to the current input-output accounting conventions, which attempt to fulfill the latter requirement, and some estimates of the solar energy inputs to the economy in an attempt to make the former requirements more complete. The calculations are performed on a 90 and 92 sector model of the U.S. economy for 1967 and results include the total fossil and solar energy intensities (in Btu/\$ output) both separately and combined as the total solar equivalents necessary to produce a dollar's worth of output in 1967.

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INTRODUCTION

All flows and storages of free energy on the earth can be thought of as embodied past and present sunlight, since sunlight is the only significant current source (ignoring tides, nuclear energy and residual heat) of free energy for the earth. Thus the sunlight of past eons is "embodied" in the current storages of fossil fuel, raw materials, soil, etc. which are employed by industrial society. It is convenient to divide the continuum of energy sources into the renewable sources of free energy (embodied present sunlight) and the nonrenewable storages (embodied past sunlight) on the basis of their relative rates of production and consumption. Renewable free energy sources are those whose rate of production roughly equals their rate of consumption. Obvious examples are sunlight itself, rain, wind and the shorter time scale products of the interaction of these inputs, such as forestry, fishery, and agricultural products. Nonrenewable sources of free energy (embodied past sunlight) are those whose rate of consumption far exceeds their rate of production. Nonrenewable sources are mined substances, such as the fossil fuels, uranium, soil storages, and mineral deposits, which are the results of slow geologic production cycles over long time periods.

The input-output (I-O) approach to calculating embodied free energy as practiced by the Energy Research Group of the Center for

Advanced Computation (CAC) at the University of Illinois (Herendeen and Bullard 1974) has thus far included only the fossil fuel, hydro-electric, and uranium sources of free energy to the U.S. economy. This paper presents the results of a first attempt to include the renewable sources of free energy to the U.S. economy as well as the theoretical justification and results of other modifications in the model dealing with the treatment of labor and government services. The intended result is quantification of the total embodied solar energy per unit of output of goods and services in the economy as well as the composition of the input by intermediate type of embodied free energy (i.e., coal, oil, gas, current sunlight, etc.).

Labor services and government services can be thought of as having energy embodied in them in the same sense that a car or any other product of the economy has energy embodied in it. They all require energy, both directly and indirectly, in order to be produced. The current conventions in I-0, which were adopted by the CAC group, treat households and government as part of the final demand sector. This implies that household and government services, which reenter the economic accounts as part of value added, have no energy embodied in them. This is obviously not the case. There are two alternatives: (1) Maintain the current conventions and calculate independently the energy embodied in labor and government services. Then add this as an energy input to the economy embodied in the household and government components of value added, or (2) Make households and government endogenous sectors by modifying the I-0 conventions and calculate their energy intensities simultaneously with the energy intensities of all the other sectors in the economy.

The second alternative was chosen since it does not require the independent calculation of the energy intensity of labor and government services. Accounting conventions are like brick walls, however. They are formidable enough to discourage attack and impossible to break down without making a mess. It is hoped that the added conceptual cleanliness will outweigh the inevitable statistical debris.

Input-Output Techniques for Calculating Embodied Energy

The application of input-output techniques to the study of direct plus indirect energy costing has been well developed and documented by the Energy Research Group at the CAC, University of Illinois (see References). The technique consists of setting up a set of energy balance equations (one for each sector) and solving the resulting set of simultaneous linear equations for the energy intensity coefficients vector $\underline{\epsilon}$.

Figure 1 shows the basic "energy balance" for a sector.

x_{ij} is the transaction from sector i to sector j .

x_j is the total output of sector j .

ϵ_j is the embodied energy intensity per unit of x_j .

E_j is the external direct energy input to sector j .

Thus the energy balance for the j^{th} component is

$$E_j = \epsilon_j x_j - \sum_i^N \epsilon_i x_{ij}$$

In matrix notation for all components

$$\underline{E} = \underline{\epsilon}(\hat{\underline{X}} - \underline{X})$$

Here $\underline{E}$ is a vector of direct external energy inputs, $\hat{\underline{X}}$ is a diagonalized vector of output flows, $\underline{X}$ is a matrix of input flows and $\underline{\epsilon}$ is the vector of total (direct plus indirect) energy embodied in a unit of outflow.

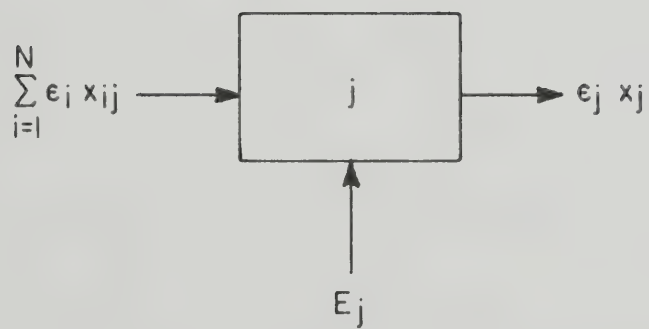


Figure 1. Single Sector Energy Balance.

We can solve for $\underline{\varepsilon}$ as

$$\underline{\varepsilon} = \underline{E} (\hat{\underline{X}} - \underline{X})^{-1}$$

A simple example will clarify the procedure. Consider a three-sector economy consisting of an energy sector, an agricultural and manufacturing sector, and a household sector with an input-output table as shown below.

	Energy	Agriculture and Manufacturing	Households	Net Exports	Total Output
Energy (Btu)	1	2	0	0	3 (Btu)
Agriculture and manufacturing (\$)	1	1	2	1	5 (\$)
Households (\$)	1	2	2	0	5 (\$)
External energy (Btu)	3	1	0		

The output of a sector to other sectors is read as a row. For example, the energy sector exports 1 Btu to itself, 2 Btu to agriculture and manufacturing, 0 Btu to households, 0 Btu to net exports for a total output of 3 Btu. The inputs to a sector are read down its column. For example, households receive 0 Btu from energy, 2 \$ from agriculture and manufacturing and 2 \$ from households.

For this example, if we include households as an endogenous sector:

$$\hat{\underline{X}} = \begin{bmatrix} 3 \text{ (Btu)} & 0 & 0 \\ 0 & 5 \text{ ($) } & 0 \\ 0 & 0 & 5 \text{ ($) } \end{bmatrix} \quad \underline{X} = \begin{bmatrix} 1 \text{ Btu} & 2 \text{ Btu} & 0 \\ 1 \$ & 1 \$ & 2 \$ \\ 1 \$ & 2 \$ & 2 \$ \end{bmatrix}$$

$$\underline{E} = \begin{bmatrix} 3 \text{ Btu} & 1 \text{ Btu} & 0 \end{bmatrix}$$

$$\hat{\underline{X}} - \underline{X} = \begin{bmatrix} 2 & -2 & 0 \\ -1 & 4 & -2 \\ -1 & -2 & 3 \end{bmatrix}$$

$$(\hat{\underline{X}} - \underline{X})^{-1} = \begin{bmatrix} 4/3 & 1 & 2/3 \\ 5/6 & 1 & 2/3 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\underline{\varepsilon} = \underline{E} (\hat{\underline{X}} - \underline{X})^{-1} = \begin{bmatrix} 3 & 1 & 0 \\ 4 & 5/6 & 2/3 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\underline{\varepsilon} = \begin{bmatrix} 4 & 5/6 \frac{\text{Btu}}{\text{Btu}}, & 4 \frac{\text{Btu}}{\text{Btu}}, & 2 \frac{2}{3} \frac{\text{Btu}}{\$} \end{bmatrix}$$

If households were considered to be exogenous, however, we would have:

$$\hat{\underline{X}} = \begin{bmatrix} 3 \text{ Btu} & 0 \\ 0 & 5 & \$ \end{bmatrix}$$

$$\underline{X} = \begin{bmatrix} 1 \text{ Btu} & 2 \text{ Btu} \\ 1 \$ & 1 \$ \end{bmatrix}$$

$$\underline{E} = [3 \text{ Btu} \quad 1 \text{ Btu}]$$

$$\hat{\underline{X}} - \underline{X} = \begin{bmatrix} 2 & -2 \\ -1 & 4 \end{bmatrix}$$

$$(\hat{\underline{X}} - \underline{X})^{-1} = \begin{bmatrix} 2/3 & 1/3 \\ 1/6 & 1/3 \end{bmatrix}$$

$$\underline{\varepsilon} = \underline{E} (\hat{\underline{X}} - \underline{X})^{-1} = [3 \quad 1] \begin{bmatrix} 2/3 & 1/3 \\ 1/6 & 1/3 \end{bmatrix} = \left[2 \frac{1}{6} \frac{\text{Btu}}{\text{Btu}}, 1 \frac{1}{3} \frac{\text{Btu}}{\$} \right]$$

which is substantially different from the result with households endogenous.

The lower energy intensities which result from an exogenous household sector are due to the fact that the household services contain embodied energy which we ignore using this approach. As mentioned earlier, an alternative to having an endogenous household sector is the independent calculation of the household services energy intensity, and the use of this coefficient to include the energy embodied in household services as an input.

In our example economy, the energy intensity of household services was calculated as $2 \frac{2}{3}$ Btu/\$ using the endogenous household approach. This number can be used to include the energy embodied in household services in the energy vector (the $\underline{E}$ vector), while leaving households exogenous. The new $\underline{E}$ vector is:

$$\underline{E} = [3 \text{ Btu} + (\$1 \times 2 \frac{2}{3} \text{ Btu}/\$), 1 \text{ Btu} + (\$2 \times 2 \frac{2}{3} \text{ Btu}/\$)]$$

$$\underline{E} = [5 \frac{2}{3} \text{ Btu}, 6 \frac{1}{3} \text{ Btu}]$$

and

$$\underline{\varepsilon} = \underline{E} (\hat{\underline{X}} - \underline{X})^{-1} = [5 \frac{2}{3}, 6 \frac{1}{3}] \begin{bmatrix} 2/3 & 1/3 \\ 1/6 & 1/3 \end{bmatrix}$$

$$\underline{\varepsilon} = \left[4 \frac{5}{6} \frac{\text{Btu}}{\text{Btu}}, 4 \frac{\text{Btu}}{\$} \right]$$

which is equivalent to the result using an endogenous household sector. This approach requires that we already know the energy intensity of household services, however.

Renewable Energy Inputs to the U.S. Economy

Figure 2 is an energy flow diagram, that is intended to show conceptually how the free energy in renewable and nonrenewable sources is distributed through an aggregated 13-sector economy. The environment sector represents all air, land, and water which has no direct economic value. This would include the atmosphere and oceans, wetlands, and wastelands--in general, all areas not in forestry, agricultural, industrial, commercial, or residential use. These areas capture renewable energy and produce environmental services which are highly diverse and difficult to measure. Services such as air and water-quality control, and urban and agricultural waste utilization are provided. These services are also carried out, in part, by the forestry and agricultural areas, which utilize large quantities of direct renewable energy.

The quantification of the distribution of environmental services throughout the economy is currently being studied by various groups, including the Energy Analysis Group led by H. T. Odum at the University of Florida. These studies are not complete enough to include in the present framework, however, and some simplifying assumptions were made for the current application, with the intention of including more detailed data as they become available.

Basically, the environment sector was partitioned between the other sectors in the economy according to land and water area. Table 1 shows the land and water use distribution for the U.S. and estimates the total solar absorption (including atmospheric) for the various uses. The agriculture sector was credited with the solar absorption over all agricultural land plus 34% of the absorption over the wetlands,

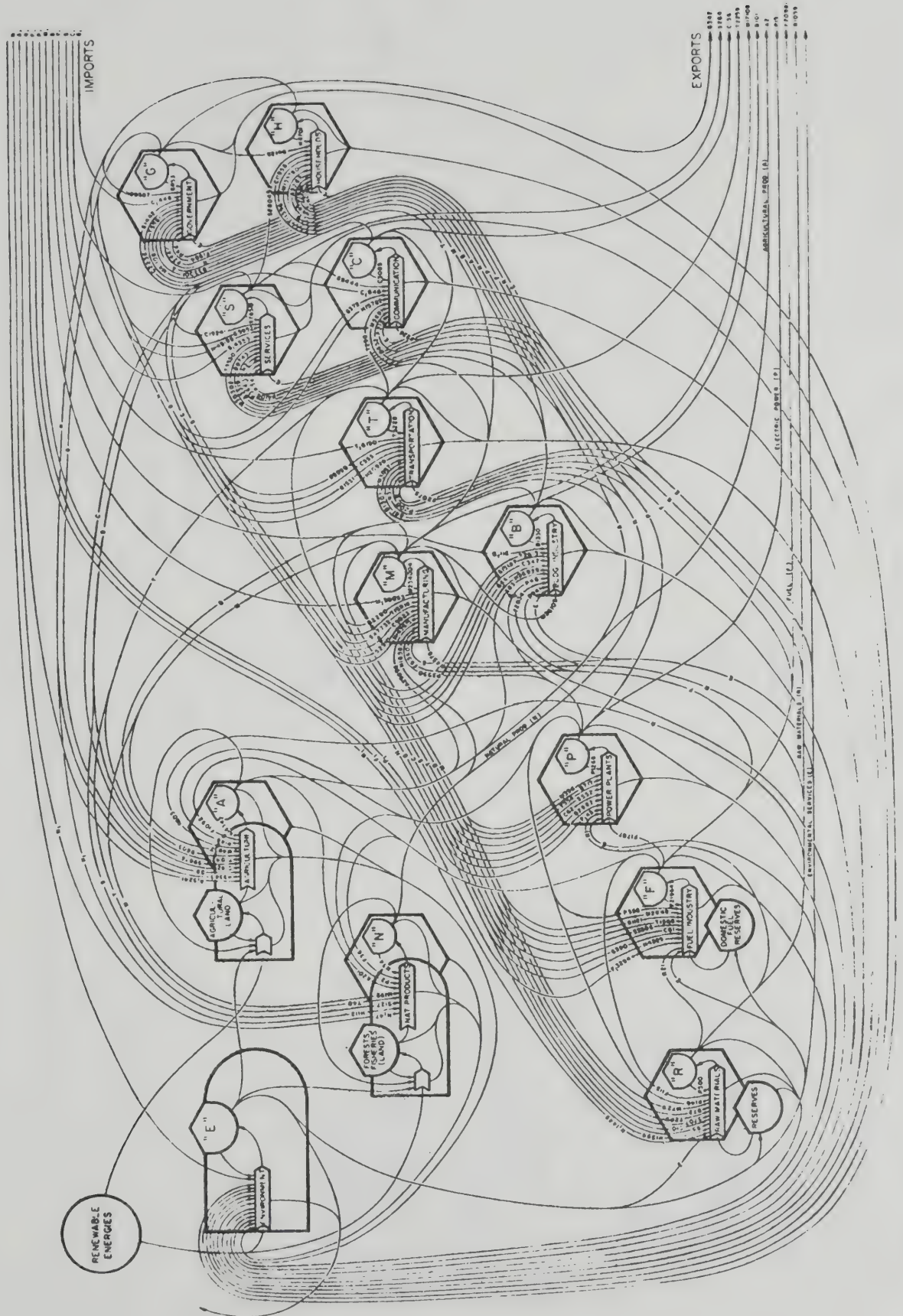


Table 1. Estimated Land Areas and Solar Absorption for Major Land Use Types.

	Area ¹ (x 10 ⁶ acres)	Average Solar Absorption ² (x 10 ⁹ Btu/ac·yr)	Total Solar Absorption (x 10 ¹⁸ Btu/yr)
Total land	2254	28	33.9
Agriculture	1212		
Cropland	384		
Grassland pasture	540		
Grazing land	288		
Forestry	587	28	16.4
Woodland pasture	62		
Woodland (not pastured)	50		
Forest land	475		
Wetlands, desert and tundra	272	20	5.4
Urban and mining	193	20	3.9
Total water	1550	28	43.4
Inland and estuarine	50		
Offshore (200 mile limit)	1500		
Total land and water	3814		103.0

¹From Historical Statistics of the U.S. USDC.

²Estimated solar absorption of the earth-atmosphere system (Budyko 1978, and Haar and Suomi 1969).

desert, and tundra category, as agriculture represents 34% of the remaining land and water use. This amounted to 35.74×10^{18} Btu solar/yr. The forestry and fisheries sector was credited with the absorption over all forested areas plus estuaries and coastal water to the 200 mile limit plus 60% of the wetlands, desert, and tundra absorption. This amounted to 63.06×10^{18} Btu/solar yr. The remaining 4.20×10^{18} Btu solar/yr represents direct utilization by the remaining industrial, commercial, residential, and governmental sectors of the economy. This should be distributed to the remaining sectors according to their total land areas. Accurate land use data are not available at this level of disaggregation, however. As an approximation, the entire 4.20×10^{18} Btu solar/yr was credited to the household category since this category represents about 75% of the remaining land area.

2. The second part outlines the specific procedures for recording and reporting these activities. It details the steps involved in data collection, analysis, and the preparation of reports for management review.

3. The third part addresses the role of the audit committee in overseeing the financial reporting process. It highlights the committee's responsibility for ensuring that the financial statements are fair, balanced, and free from material misstatements.

4. The fourth part discusses the importance of internal controls in preventing and detecting errors or fraud. It describes how a robust system of internal controls can help the organization achieve its objectives and maintain the integrity of its financial information.

5. The fifth part provides a summary of the key findings and recommendations from the audit. It identifies areas where improvements are needed and offers practical suggestions for addressing these issues.

6. The final part of the document concludes with a statement of the audit team's independence and objectivity. It reaffirms the team's commitment to providing an unbiased and reliable assessment of the organization's financial health.

Government and Households as Endogenous Sectors

It is my intention to treat the household and government sectors and all the other sectors in the economy alike, so that the energy embodied in their services may be included in the calculation of total embodied energy for the U.S. economy. The household sector's inputs from the other sectors are measured as personal consumption expenditures (PCE), which are the dollar payments of individuals for goods and services. The exception is the input to households of government services that are paid for with federal income taxes, along with state and local government taxes on households. The outputs of the household sector to the other sectors are labor services that are measured by the employee compensation of workers. Complications arise since the input-output accounts break value added (or VA, defined as the payments to the factors of production) into only three categories: (1) employee compensation, (2) indirect business taxes and (3) property type income. Table 2 shows the relationship of these categories to the national income and product accounts categories. The implied wages of self-employed people or unpaid family workers are not directly included in the employee compensation category, but show up as a portion of proprietor's income which is embedded in the property-type income category of value added.

Similarly, corporate profits taxes, which are also embedded in property type income, should be added to indirect business taxes to determine the total taxes paid by business to government. Table 3 shows the breakdown of property type income for the economy as a whole in 1967 and those portions attributable to households and

Table 2. Relationship of Input-Output Value Added Components to the National Income and Product (NIP) Accounts Categories.

I-O Value Added Component	NIP Accounts
Employee compensation	Employee compensation
Indirect business taxes	Indirect business taxes and nontax liability
Property-type income	Proprietors income
	Rental income of persons
	Corporate profits (before taxes) and inventory valuation adjustment
	Net interest
	Business transfer payments
	Surplus of government enterprises less subsidies
	Capital consumption allowances

Table 3. 1967 Property Type Income Breakdown by National Income Categories.

	Billions of 1967 \$	Percent of Total	Sector Destination Households or Government
Total property-type income	255.2	100.0	
Proprietors income	62.1	24.3	.75 to households
Business and professional	47.3	18.5	
farm	14.8	5.8	
Rental income of persons	21.1	8.4	
Corporate profits and inventory valuation adjustment	78.7	30.9	
Profits before tax	79.8	31.3	To government
Profits tax liability	33.2	13.0	
Profits after tax	46.6	18.3	
Dividends	21.4	8.4	
Undistributed profits	25.3	9.9	
Inventory valuation adjustment	-1.1	-.4	
Net interest	24.1	9.4	
Capital consumption allowances	28.9	27.0	

Source: Statistical Abstract of the U.S. 1971 ed., p. 309.

government. Proprietor's income must be split between the return for the proprietor's labor services and the return for his capital (i.e., his store or farm capital). A rough figure of 75% return to labor was used based on labor's share of the total return in the U.S. economy. The data in Table 3 are summarized in Table 4, which shows estimates of the sector destinations of the aggregate property-type income for the U.S. economy in 1967. Households received 18.3% of the total as their share of proprietor's income, while government received 13.0% as corporate profits taxes.

The I-0 accounting framework requires that the sum of the total dollar value of the outputs from a sector equal the sum of the dollar value of the inputs. This requirement was used to set up accounting identities for the new household and government sectors that could be solved for the percentages of property type income, which should be credited to each sector in order to balance the accounts.

For the government sector we can write:

$$IBT + X(PTI) + PT = GP + GS.$$

Here for 1967 (in millions of \$)

$$IBT = \text{Indirect business taxes} = 70239$$

$$PTI = \text{Property type income} = 254060$$

$$PT = \text{Personal taxes} = 83000$$

$$GP = \text{Government purchases} = 97465$$

$$GS = \text{Government salaries} = 81654$$

So the fraction of PTI to government necessary to balance the sector's accounts is:

$$X = \frac{GP + GS - IBT - PT}{PTI} = \frac{97465 + 81654 - 70239 - 83000}{254060}$$

$$X = .1019$$

Table 4. 1967 Sector Destination Breakdown of Property Type Income.

	Billions of 1967 \$	Percent of Total
Total property-type income	255.2	100.0
Households	46.6	18.3
Government	33.2	13.0
Payments to resources and land	106.5	41.7
Capital consumption allowances	68.9	27.0

For the household sector we can write:

$$EC + X(PTI) + GS = PCE + PT$$

where for 1967 (in millions of \$)

$$EC = \text{Employee compensation} = 389436$$

$$PTI = \text{Property type income} = 254060$$

$$GS = \text{Government salaries} = 81654$$

$$PCE = \text{Personal consumption expenditures} = 490660$$

$$PT = \text{Personal taxes} = 83000$$

So, the percentage of PTI to households necessary to balance the sector's account is:

$$X = \frac{PCE + PT - EC - GS}{PTI} = \frac{490660 + 83000 - 389436 - 81654}{254060}$$

$$X = .4037$$

This leaves $1 - .1019 - .4037 = .4944$

as the fraction of PTI remaining in the redefined value added category. The new value added category contains only capital consumption allowances and payments to land and resources.

Summary of Modifications

Figure 3 graphically shows the modifications to the I-O conventions necessary to make government and households endogenous sectors. The outputs of government and labor services to the other 90 sectors had to be estimated as shown in the figure due to the incomplete breakdown of value added available from BEA for the input-output accounts. The accounts are constantly being improved and better data in this area may be forthcoming. At any rate, improvements in coverage can be incorporated into future studies. This study can only point up areas where better data are needed and make do with existing data.

	I-O Sectors (90)	GOVERNMENT	HOUSEHOLDS	GROSS CAPITAL FORMATION	NET INVENTORY CHANGE AND NET EXPORTS	TOTAL OUTPUT
I-O Sectors (90)	Current "total transactions" matrix	Government purchases of goods and services	Personal consumption expenditures			
Government	Indirect business taxes + .1019*PTI		Personal tax			
Households	Employee compensation + .4037*PTI	Government salaries				
Capital consumption allowances and payments to land and resources	.4944*PTI					
Total Inputs						

Figure 3. Summary of Modification to I-O Conventions.

RESULTS

90-Sector Energy Intensities without Government and Labor Feedbacks or Solar Energy Inputs

Table 5 lists the energy intensities (in Btu fossil/\$) for a 90-sector economy which includes neither government and labor service feedbacks nor solar energy inputs. This is the previous approach of the Energy Research Group and is presented here for comparison (Herendeen and Bullard 1974). The results presented here differ from that study in one respect. Dollar flows were used throughout in the present study whereas, in the previous study, direct energy flows were used to measure the distribution of fossil fuels, hydro, and nuclear energy from the energy sectors to the remaining sectors.

The use of direct energy flows is preferable if the output from the energy sectors are physically homogenous (which is a fair approximation for the fossil fuel producing sectors). Including solar energy inputs to the economy requires, however, that we create energy sectors whose output is physically very nonhomogenous (such as agricultural products) and for which dollar flows are the best weighted aggregate available. In order to maintain consistency, dollar flows were used throughout.

As in the previous study, the "Primary" column represents the total fossil fuel Btu's (or total solar Btu's in subsequent results) but is not simply the sum of the individual energy sector contributions.

This is necessary to avoid double counting, since refined is produced from crude, some electricity is produced from coal and crude, etc. In this study the total primary fossil fuel energy

intensity was calculated using the formula:

$$\epsilon_{\text{Primary}} = \epsilon_{\text{Coal}} + \epsilon_{\text{Crude and gas}} + .61652 (\epsilon_{\text{Electricity}})$$

where the factor .61652 accounts for the fraction of electricity produced from hydro or nuclear sources (Herendeen and Bullard, 1974).

The primary fossil fuel energy intensity column of Table 5 exhibits the following statistics:

Mean = 183080 Btu fossil/\$

Standard deviation = 628170 Btu fossil/\$

Coefficient of variation = 3.43

The coefficient of variation is the standard deviation divided by the mean. It is a measure of dispersion useful for comparing two populations whose values are of different orders of magnitude.

Table 5. 90-Sector Energy Intensities without Government
and Labor Feedbacks or Solar Energy Inputs.

SECTOR	COAL	CRUDE	REFINED	ELECTRICITY	GAS	UTILIT	PRIMARY
COAL MINING	-51103E+07	-29481E+05	-19610E+05	-62426E+04	-68678E+04	-68678E+04	-51436E+07
CRUDE PETRO. GAS	-71551E+04	-29110E+07	-82638E+04	-25157E+04	-98124E+04	-98124E+04	-29203E+07
PETRO REFIN. PROD	-96845E+04	-14105E+07	-10300E+07	-33822E+04	-31212E+05	-31212E+05	-19223E+07
ELECTRIC UTIL	-29845E+04	-61710E+05	-22754E+05	-23575E+04	-31603E+05	-31603E+05	-50555E+06
GAS UTILITIES	-58077E+04	-61243E+06	-55993E+05	-18443E+04	-20033E+05	-20033E+05	-80933E+06
WAS. UTILITIES	-79211E+04	-7270E+05	-52994E+05	-20190E+04	-28033E+05	-28033E+05	-81565E+06
FISH. AG. PRODUCTS	-76251E+04	-53928E+05	-39950E+05	-11533E+04	-56979E+05	-56979E+05	-62565E+06
FORM. AG. PROD	-85097E+04	-45753E+05	-36737E+05	-23408E+04	-76951E+05	-76951E+05	-52270E+06
LIV. STOCK	-55010E+04	-37199E+05	-18494E+05	-11330E+04	-55311E+05	-55311E+05	-32997E+06
AW. FARM. FISH. SER	-32424E+04	-3903E+05	-14994E+05	-8795E+04	-55311E+05	-55311E+05	-65904E+06
IRON ORE MINING	-29242E+04	-37199E+05	-14994E+05	-8795E+04	-55311E+05	-55311E+05	-65904E+06
STONE CLAY MIN	-31910E+04	-36243E+05	-17375E+05	-9695E+04	-15237E+05	-15237E+05	-61037E+06
CHEM. MINERAL MIN	-16572E+04	-36243E+05	-17375E+05	-9695E+04	-15237E+05	-15237E+05	-61037E+06
NEW CONSTRUCTION	-17229E+04	-36243E+05	-17375E+05	-9695E+04	-15237E+05	-15237E+05	-61037E+06
MAINT. REPAIR CONST	-14474E+04	-36243E+05	-17375E+05	-9695E+04	-15237E+05	-15237E+05	-61037E+06
MANUFACTURE	-18623E+04	-21411E+05	-20971E+05	-10399E+04	-12730E+05	-12730E+05	-54804E+06
FOOD	-14253E+04	-36655E+05	-13042E+05	-28123E+04	-10773E+05	-10773E+05	-47798E+06
TOBACCO	-64367E+04	-22422E+05	-15803E+05	-11844E+04	-51142E+05	-51142E+05	-30099E+06
PAPER & PAPER MILLS	-21495E+04	-45221E+05	-17509E+05	-51620E+04	-10300E+05	-10300E+05	-69150E+06
TEXTILE GOODS	-20020E+04	-45221E+05	-17509E+05	-51620E+04	-10300E+05	-10300E+05	-69150E+06
APPAREL	-12401E+04	-24371E+05	-15443E+05	-32608E+04	-98952E+05	-98952E+05	-67389E+06
FEED & FEEDING	-17233E+04	-30047E+05	-10379E+05	-40423E+04	-14317E+05	-14317E+05	-38445E+06
WOOD PRODUCTS	-12401E+04	-30047E+05	-10379E+05	-40423E+04	-14317E+05	-14317E+05	-38445E+06
WOOD CONTAINERS	-1740E+04	-30047E+05	-10379E+05	-40423E+04	-14317E+05	-14317E+05	-38445E+06
H. WOOD FURNITURE	-17294E+04	-30047E+05	-10379E+05	-40423E+04	-14317E+05	-14317E+05	-38445E+06
PUMPS, FIXTURES	-2601E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PAPER, PAPER MILLS	-4121E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PAPERBOARD CONT.	-37603E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PAPERBOARD CONT.	-12550E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PRINTING, PUBL.	-36310E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
CHEM. PRODUCTS	-36310E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PLASTICS	-15542E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PAINTS	-24129E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PAVING	-41129E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
ASPHALT	-41129E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
RUBBER	-54239E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
LEATHER PRODUCTS	-19522E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
FOOTWEAR	-30635E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
GLASS PRODUCTS	-41474E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
STONE CLAY. PROD	-45031E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
SPIN. IR. SIL. MANU	-15109E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PRIM. COPPER MET.	-24219E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
HEATING CONTAINERS	-12495E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
HEATING PLYMBING	-47500E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
SCHEM. MACH. PROD	-39550E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PAD. MACH. PROD	-32590E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
ENG. MACH. TOOLS	-36993E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
PART. MACHINERY	-38593E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
CONST. MILLING EQ	-31360E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
MACH. HANDLING EQ	-24537E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
REINWORKING EQ	-25941E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
SPEC. IND. MACH	-29040E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
GEN. IND. MACH	-22949E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
MACH. SHUT. PROD	-11735E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
OPC. COMP. MACH	-26615E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
SERVICE IND. MACH	-22113E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
ELEC. IND. APPLANCE	-29101E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
H. WOOD APPLANCE	-22911E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06
ELEC. LIGHT EQ	-22911E+04	-43971E+05	-11746E+05	-31960E+04	-11598E+05	-11598E+05	-42521E+06

R-TV COMMUN EQ	105932E+05	87270E+04	23580E+04	83586E+04	26959E+05
ELECTRONIC EQUIP	14199E+05	11131E+05	33817E+04	13070E+05	36165E+05
ELECTRONIC EQUIP	19032E+05	12611E+05	35873E+04	15717E+05	44233E+05
MOTOR VEH C PARTS	31351E+05	11560E+05	33158E+04	15018E+05	54469E+05
AIRCRAFT C EQUIP	19935E+05	12501E+05	26722E+04	91588E+04	35540E+05
TRANSPORT EQUIP SUPP	22471E+05	12210E+05	35769E+04	16410E+05	57905E+05
PROF. SCIENT. SUPPLIES	33230E+05	12249E+05	28769E+04	11309E+05	37380E+05
OPTICAL SUPPLIES	10000E+05	12367E+05	23809E+04	10501E+05	32033E+05
MISC. MACH. SUPP	18468E+05	37139E+05	23049E+04	12023E+05	45403E+05
RAILROAD TRANSPORT	80462E+04	57139E+05	23450E+04	77016E+04	60219E+05
LOCAL INTL TRANSP	79489E+04	57139E+05	24083E+04	74772E+04	66240E+05
MOTOR FUEL TRANSP	43004E+04	57139E+05	93837E+03	48452E+04	80561E+05
WATER TRANSPORT	14780E+05	56600E+05	24355E+04	11775E+05	85647E+05
AIR TRANSPORT	42131E+04	89019E+05	13463E+05	73721E+04	12203E+06
PIPE LINE TRANSP	19751E+05	23555E+05	13115E+05	32127E+04	13293E+06
TRANSP. SERVICES	23301E+04	17209E+04	53829E+03	14899E+04	56723E+04
COMMUNICATIONS	29335E+04	61820E+04	14913E+04	40332E+04	13571E+05
R-TV BROADCAST	64740E+05	63137E+05	14913E+04	90512E+04	20722E+05
WATER, SANIT. SER	20733E+05	15667E+05	98155E+04	57162E+05	68101E+05
WHOLESALE TR	60621E+04	13025E+05	31343E+04	67316E+04	29302E+05
FINANCIAL TR	44941E+04	11552E+05	21500E+04	61737E+04	29302E+05
REAL ESTATE	21140E+05	11702E+05	47494E+03	41093E+04	26362E+05
HOTELS, RESTAUR.	29400E+05	19914E+05	38131E+04	11003E+05	41834E+05
BUSINESS SERVICE	13930E+05	95221E+05	15930E+04	82700E+04	23140E+05
AUTO REPAIR	2010E+05	19163E+05	26157E+04	87003E+04	42217E+05
ADJ. REPAIRS	15091E+05	96832E+05	25257E+04	67003E+05	22217E+05
MED. EQUIP. ENTERP	18039E+05	10013E+05	55299E+04	14059E+05	22251E+05
FED. GOV. ENTERP	22539E+05	14914E+05	19555E+04	80733E+05	27503E+05
ST. LOC. GOV. TRAVEL	46001E+05	17162E+05	35501E+04	59533E+05	61893E+05
BUSINESS TRAVEL	59014E+05	42515E+05	26301E+04	10079E+05	69697E+05
OFFICE SUPPLIES	19660E+05	16304E+05	32390E+04	14802E+05	49223E+05
GOVERNMENT	0.	0.	0.	0.	0.
HOUSEHOLDS	0.	0.	0.	0.	0.

90-Sector Energy Intensities without Government and Labor Feedbacks
Including Solar Energy Inputs

Table 6 lists the energy intensities (in Btu/\$) for a 90-sector economy, which includes solar energy inputs but neglects labor and government services feedbacks. The solar energy is embodied in the outputs of the agriculture and forestry and fisheries sectors.

The total primary solar energy intensity column for this model is calculated thus:

$$\epsilon_{\text{primary}} = 2000 [\epsilon_{\text{coal}} + \epsilon_{\text{crude and gas}} + .61652 (\epsilon_{\text{electricity}})] \\ + \epsilon_{\text{agriculture}} + \epsilon_{\text{forestry and fisheries}}$$

where the .61652 factor again accounts for the fraction of electricity produced from hydro and nuclear sources (Herendeen and Bullard, 1974), and the 2000 factor accounts for the Btu's of solar energy embodied in a Btu of fossil fuel energy (Odum et al., 1977).

The primary solar energy intensity column of Table 6 exhibits the following statistics:

$$\text{Mean} = 1087.7 \times 10^6 \text{ Btu solar}/\$$$

$$\text{Standard deviation} = 5016.5 \times 10^6 \text{ Btu solar}/\$$$

$$\text{Coefficient of variation} = 4.61$$

Table 6. 90-Sector Energy Intensities without Government
and Labor Feedbacks but Including Solar Energy
Inputs.

[illegible]

92-Sector Energy Intensities with Government and Labor Feedbacks
Excluding Solar Energy Inputs

Table 7 lists the energy intensities (in Btu fossil/\$) for a 92-sector economy, which includes government and labor feedbacks but neglects solar energy inputs. The total primary energy intensity (in Btu fossil/\$) for this alternative is calculated as:

$$\epsilon_{\text{primary}} = \epsilon_{\text{coal}} + \epsilon_{\text{crude and gas}} + .61652(\epsilon_{\text{electricity}})$$

where, as before, the .61652 factor accounts for the fraction of electricity produced from nuclear and hydro sources.

The primary fossil fuel energy intensity column of Table 7 exhibits the following statistics:

$$\text{Mean} = 515610 \text{ Btu fossil}/\$$$

$$\text{Standard deviation} = 618910 \text{ Btu fossil}/\$$$

$$\text{Coefficient of variation} = 1.20$$

Table 7. 92-Sector Energy Intensities with Government and
Labor Feedbacks but Excluding Solar Energy Inputs.

[illegible]

92-Sector Energy Intensities with Government and Labor Feedbacks and Solar Energy Inputs

Table 8 lists the energy intensities (in Btu/\$) in 1967 for a 92-sector economy, which includes government and labor services feedbacks and solar energy inputs. The total primary solar energy intensity (in Btu solar/\$) for this alternative is calculated as:

$$\epsilon_{\text{primary}} = 2000 [\epsilon_{\text{coal}} + \epsilon_{\text{crude and gas}} + .61652 \epsilon_{\text{electricity}}] \\ + \epsilon_{\text{agriculture}} + \epsilon_{\text{forestry and fisheries}} + \epsilon_{\text{households}}$$

where the .61652 factor accounts for the fraction of electricity produced from nuclear and hydro sources (Herendeen and Bullard, 1974) and the 2000 factor converts from fossil fuel to embodied solar energy (Odum et al., 1977).

The primary solar energy intensity column of Table 8 exhibits the following statistics:

$$\text{Mean} = 2435.3 \times 10^6 \text{ Btu solar}/\$$$

$$\text{Standard deviation} = 4936.6 \times 6 \times 10^6 \text{ Btu solar}/\$$$

$$\text{Coefficient of variation} = 2.0$$

Table 8. 92-Sector Energy Intensities with Government
and Labor Feedbacks and Solar Energy Inputs.

[illegible]

DISCUSSION AND CONCLUSIONS

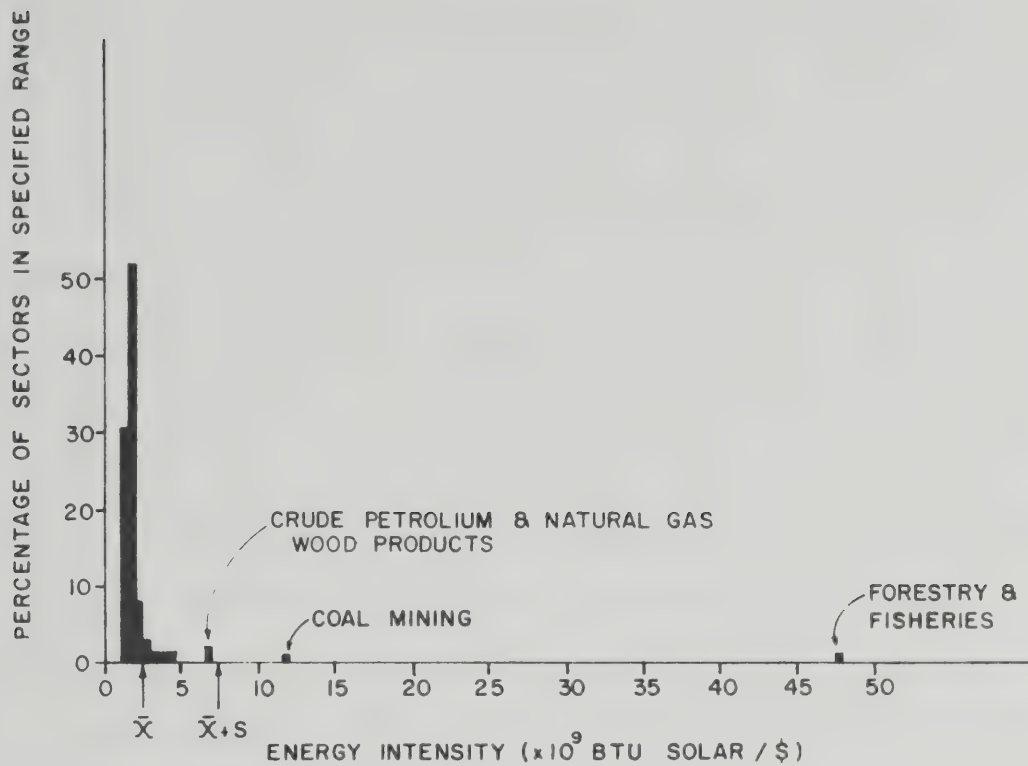
Understanding the relationship between the energy inputs to an economy and the dollar value of its outputs is becoming more important as our energy sources become depleted. The input-output technique is useful in assessing the total direct and indirect energy necessary to produce goods and services in an economy. This paper contains results of modifications to the input-output method for obtaining energy intensities (Herendeen and Bullard, 1974). The modifications are aimed at achieving consistency with the boundary definitions of the economy. The results indicate that inclusion of labor and government services feedbacks significantly reduce the variation in energy intensities and increase their average magnitude, while inclusion of solar energy inputs increased both the variation and magnitudes. Comparison of the two alternatives without solar energy inputs (Tables 5 and 7) show a reduction in the coefficient of variation from 3.4 to 1.2 with the inclusion of labor and government services feedback, and a corresponding increase from 1.86×10^5 to 5.16×10^5 Btu fossil/\$ in the mean energy intensity. Similarly, the two alternatives with solar energy (Tables 6 and 8) show a reduction in the coefficient of variation from 4.6 to 2.0 with the inclusion of labor and government services feedbacks, and a corresponding increase from 1.09×10^9 to 2.44×10^9 Btu solar/\$ in the mean energy intensity. Comparison of the two alternatives without labor and

government services feedbacks (Tables 5 and 6) show an increase in the coefficient of variation from 3.4 to 4.6 with the inclusion of solar energy inputs and a corresponding increase from $.37 \times 10^9$ to 1.09×10^9 Btu solar/\$ in the mean energy intensity.* Similarly, the two alternatives with labor and government services feedbacks (Tables 7 and 8) show an increase in the coefficient of variation from 1.2 to 2.0 with the inclusion of solar energy inputs and a corresponding increase from 1.03×10^9 to 2.44×10^9 Btu solar/\$ in the mean energy intensity.*

As noted earlier, the distribution of solar energy inputs to the economic sectors is imperfectly known and only a crude approximation was used in this study. Since the total magnitude of solar energy absorbed by the U.S. in 1967 is fairly well known, the inclusion of solar energy in the manner adopted in this study may distort the distribution of embodied solar energy due to imperfect knowledge of the input distribution. For example, the total primary energy intensity of forestry and fisheries products (sector 7) is an extreme outlier at 47.7×10^9 Btu solar/\$ compared to a mean of 2.4×10^9 Btu solar/\$ in Table 8. This is probably due to an overestimate of the solar energy input to this sector relative to other sectors.

The statistics on the total primary energy intensities are somewhat misleading. Figure 4 is a frequency plot of the total primary energy intensities given in Table 8. The mean was calculated as 2.44×10^9 Btu solar/\$ with a standard deviation of 4.94×10^6

*In solar equivalents using the conversion factor: 2000 Btu solar/Btu fossil (Odum et al., 1977).



Range ($\times 10^9$ Btu Solar/\$)	Frequency
0 - 0.5	-
.5 - 1.0	-
1.0 - 1.5	.304
1.5 - 2.0	.520
2.0 - 2.5	.076
2.5 - 3.0	.030
3.0 - 3.5	.010
3.5 - 4.0	.010
4.0 - 4.5	.010
. - .	.
. - .	.
. - .	.
6.5 - 7.0	.020
. - .	.
. - .	.
11.5 - 12.0	.010
. - .	.
. - .	.
. - .	.
47.5 - 48.0	.010

Figure 4. Frequency Plots of Total Primary Energy Intensities Including Labor and Government Services Feedbacks and Solar Energy Inputs (Table 8).

Btu solar/\$. The frequency plot shows that the numbers are much more clustered than these statistics would indicate. This could be due to a nonnormal population distribution. If the population were normal, the mean plus one standard deviation on both sides should include about 68% of the observations. Figure 4 shows that the mean plus one standard deviation includes 98% of the sample points. If the outliers are eliminated by including only nonenergy sectors in the statistics then the mean for the total primary energy intensities in Table 8 drops to 1.7×10^9 Btu solar/\$ with a standard deviation of 0.70×10^9 Btu/\$ and a coefficient variation of 0.41. Table 9 summarizes the statistics on the total primary energy intensity vectors for the four alternatives both including and excluding the energy sectors.

It was stressed earlier that many conceptual and empirical refinements to the technique remain to be made. There are problems with capital flows, incomplete coverage, joint products, and transfers, and there is the need for much better data on the distribution of renewable energy inputs. At this point, however, some speculation on the admittedly imperfect present results may be tolerated.

In general, the results indicate a large reduction in the variation, from sector to sector, of the energy intensities with the inclusion of labor and government services feedbacks. There is a question as to whether this phenomena is a result of some underlying economic forces or is merely an artifact of the computational techniques as the economy is made more "closed." While the second possibility cannot be completely ruled out at present, we notice that in the example economy described earlier there was no tendency

Table 9. Total Primary Energy Intensity Statistics.

	Including Energy Sectors			Excluding Energy Sectors		
	$\bar{x}$	s	C.V.	$\bar{x}$	s	C.V.
<u>Alternative 1</u>						
Excluding solar inputs and labor and government (Btu fossil/\$)	1.83×10^5	6.28×10^5	3.43	6.68×10^4	5.20×10^4	0.78
<u>Alternative 2</u>						
Including solar inputs but excluding labor and government (Btu solar/\$)	1.09×10^9	5.02×10^9	4.61	3.55×10^8	10.09×10^8	2.81
<u>Alternative 3</u>						
Including labor and government but excluding solar inputs (Btu fossil/\$)	5.16×10^5	6.19×10^5	1.20	4.05×10^5	0.91×10^5	0.22
<u>Alternative 4</u>						
Including solar inputs and labor and government (Btu solar/\$)	2.44×10^9	4.9×10^9	2.00	1.7×10^9	0.70×10^9	0.41

for the energy intensity values to converge when the household sector was made endogenous. Since the numerical values for the example were chosen arbitrarily, some underlying economic force which was not present in the example might be implicated as the cause for the convergence of the energy intensity values in the real economy.

One hypothesis is that the crosssectional energy intensities measured in direct plus indirect total Btu/\$ should be constant at a point in time and that departures from the true value can be attributed to imperfections in the data or in the technique. A constant total embodied energy to dollar ratio would imply an embodied energy theory of economic value. Some additional explanation may serve to demonstrate the reasonableness of this proposition. Two assumptions are required. First, that all things may be considered as forms of energy or embodied energy. This is the basis of the I-O technique for energy analysis and the present calculations. Second, that energy is the ultimate scarce resource. Since all things are considered to be energy or embodied energy, the second assumption follows from the first. There is no possibility of substitution of "something else" for embodied energy since everything can be quantified according to its embodied energy content. The second law of thermodynamics provides the basic support for the use of energy as the ultimate scarce resource. It tells us that systems isolated from a source of energy cannot maintain their internal order against entropic deterioration.

Once energy is accepted as the ultimate scarce resource, energy cost must be accepted as the ultimate cost. An economic system concerned with the allocation of scarce resources must equate energy cost (or embodied energy) with dollar cost in order to maximize

productivity. This is what the present results may be indicating. The dollar value of commodities may be an indirect measure, via the market and price mechanism, of the total energy embodied in the commodities. Another way of stating this is that a crosssectionally constant energy intensity vector might be an indication of an economy which is maximizing its productivity by using the market and price system to equate total embodied energy with dollars. Of course neither our analysis nor the price mechanism itself are perfect, and a perfectly constant energy intensity vector would not be expected. The most glaring outliers in the present results can be explained as the result of gross data inaccuracies or external price controls. For example, the forestry and fisheries sector and the associated wood products sector are probably high due to an overestimate of the solar energy input to forestry and fisheries. The crude petroleum and natural gas sectors and coal mining are known to be subject to price controls holding the value of their output below the market price level. This leads to fewer dollars being associated with the same embodied energy and a larger value of the Btu/\$ ratio for these sectors. Future studies may incorporate more accurate data, correct any conceptual errors in the present analysis, compensate for imperfections in the price system, and perform sensitivity analysis to determine the validity of the results and speculations presented here.

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